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Incidental Catch of Marine Birds and Mammals in Fishing Nets off Newfoundland, Canada

JOHN F. PIATT*‡ and DAVID N. NETTLESHIP†
**Newfoundland Institute for Cold Ocean Science, Memorial University of Newfoundland, St. John's, Newfoundland, Canada, A1B 3X7*
†Seabird Research Unit, Canadian Wildlife Service, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, Nova Scotia, Canada, B2Y 4A2
‡Present address: Alaska Fish & Wildlife Research Center, 1011 East Tudor Road, Anchorage, AK 99503, USA

Summer surveys of the incidental catch of marine birds and mammals in fishing nets around the east coast of Newfoundland indicated that over 100 000 animals were killed in nets during a 4-year period (1981–1984). Composition of catches depended on foraging behaviour, regional abundance, and the degree of foraging aggregation of different species. Highest incidental catches occurred in conjunction with the inshore spawning migration of capelin (*Mallotus villosus*), and the numbers of capelin predators caught varied with capelin abundance. Seabird by-catch was highest in the vicinity of major breeding colonies, decreasing rapidly with distance from these sites. In some years and locations, net-mortality may have constituted the greatest source of adult mortality for some species' populations.

There is a growing body of knowledge on marine bird and mammal mortality associated with commercial fishing operations. Over the past two decades, many millions of marine animals have been drowned in fishing nets in coastal and offshore areas of the Atlantic (Bibby, 1972; Tull *et al.*, 1972; Christensen & Lear, 1977; Brun, 1979; Piatt *et al.*, 1984; Olden *et al.*, 1985) and Pacific Oceans (Ainley *et al.*, 1981; Anon, 1982; Heneman, 1983, 1984; Carter & Sealy, 1984). The known and potential impact of net-mortality on specific populations, as well as factors influencing species composition and the magnitude of net catches, have been described in the above reports and elsewhere (Evans & Waterson, 1976; King *et al.*, 1979; Piatt & Reddin, 1984; King, 1984; Ogi, 1984; Piatt & Nettleship, 1985; Evans & Nettleship, 1985; Nettleship & Evans, 1985; Carter 1986). Although the impact of discarded or lost fishing gear has been much more difficult to quantify, the few data available suggest that lost gear may be as efficient at killing animals as active gear (DeGange & Newby, 1980; Jones & Ferrero, 1985).

This paper reports on the catch of marine birds and mammals in fishing nets around the east coast of Newfoundland during four summers, 1981–1984. In particular, we focus on species composition of catches, sources of temporal and spatial variability of catches, and the potential impact of net-mortality at the population level. We identify and discuss the key factors influencing net-mortality and those species most vulnerable to entrapment in active or discarded fishing gear.

Methods

Information on net-mortality was obtained with the co-operation of fishermen living in communities adjacent to major seabird colonies in Newfoundland (Fig. 1). Detailed records of catches of marine birds and mammals, including numbers and types of nets used, areas and depths fished, and species and numbers caught, were maintained by 24 fishermen from early

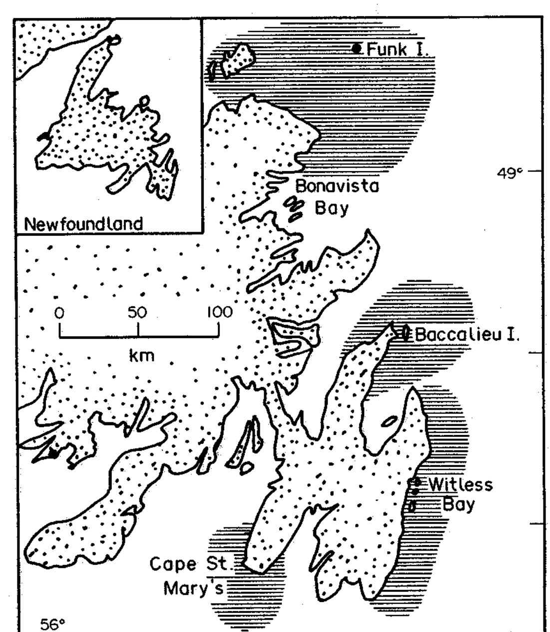

Fig. 1. Areas of eastern Newfoundland where net-mortality surveys were conducted (shading indicates marine areas where net-catches were recorded).

June to mid-August in each year of study (49 700 net-days of effort). Summary information on fishing effort and total catches was obtained from an additional 56 fishermen (182 600 net-days). Total fishing effort was estimated for each community based on information from participating fishermen. Total catches of birds and mammals were extrapolated from reported catch per effort statistics to total fishing effort in each area. Because the species composition of catches varied with the type of net used and between study areas, total catch extrapolations were calculated separately for each species (Piatt *et al.,* 1984). To corroborate catch records kept by fishermen, we directly observed some catches (consisting of over 15 000 animals) at sea and/or brought in to fishing wharves over all years of study.

Species composition of catches

Three main factors appeared to influence the species composition of catches:

1. The catch of some species was partly a function of their regional abundance. About 800 000 common guillemots breed in eastern Newfoundland (Nettleship, 1980), and they were the most numerous seabird caught in nets (Table 1). Over five million greater shearwaters migrate into Newfoundland waters in summer (Brown *et al.,* 1975) and they were estimated to be the second most common bird taken in nets (Table 1). Similarly, puffins and black guillemots are locally abundant breeders whereas razorbills are scarce (Nettleship, 1980) and this was reflected in catch records (Table 1). Harp and harbour seals are the most common pinnipeds in eastern Newfoundland and were frequently taken in nets whereas grey (*Halichoerus grypus*) and hooded seals, uncommon in eastern Newfoundland, were never or rarely taken, respectively (Table 1). These results parallel the findings of Ainley *et al.,* (1981) that catches of certain seabirds in the Pacific (e.g., short-tailed shearwaters *Puffinus tenuirostris,* and Brunnich's guillemots) were significantly correlated with their measured abundance at sea.

2. The foraging behaviour and diving ability of each species determined its vulnerability to entrapment in different types of fishing gear. Many abundant seabirds were rarely caught in nets because they are surface feeders with limited or no diving ability (e.g., storm-petrels, *Larus* gulls and kittiwakes). Surface feeders were taken only in surface-set salmon gill-nets and cod traps (Table 1). Plunge-diving gannets were caught only in salmon gill-nets (Table 1), probably while feeding on shoals of capelin near shore.

Species which pursue their prey underwater (loons, shearwaters, and alcids) were those most commonly killed in fishing nets (Table 1). Most shearwaters were caught while scavenging from cod gill-nets (Table 1) as they were being set or retrieved, but some records indicate entanglement occurred in stationary gear set at depths to 30 m (Table 2). Despite their shallow diving behaviour, shearwaters were rarely taken in surface-set salmon gill-nets (Table 1) because they infrequently venture close to the coastline where most salmon nets are deployed in Newfoundland. This contrasts with the drift-net salmon fishery in the Pacific where shearwaters comprised the majority of birds taken in nets set offshore (Ainley *et al.,* 1981).

Within the Atlantic alcids, maximum diving depth is positively correlated with body size (Piatt & Nettleship, 1985). Thus, small shallow-diving (Table 2) black guillemots were caught more frequently in surface-set salmon gill-nets than bottom-set cod gill-nets (Table

TABLE 1

Recorded, estimated, and average catch of marine birds and mammals in fishing nets off eastern Newfoundland, 1981–1984.

Species	Total no. recorded	Total no. estimated	Average per year	% in net-type* Cgn	Sgn	Ct	Fgn
Common Loon *(Gavia immer)*	26	629	157	20	80	0	0
Greater Shearwater *(Puffinus gravis)*	1025	8926	2232	96	4	0	0
Sooty Shearwater *(Puffinus griseus)*	201	1750	438	95	5	0	0
Leach's Storm-petrel *(Oceanodroma leucorhoa)*	17	195	49	0	100	0	0
Northern Gannet *(Sula bassana)*	40	1710	428	0	100	0	0
Cormorant *(Phalacrocorax* spp.*)*	2	‡	‡	100	0	0	0
Common Eider *(Somateria mollissima)*	23	278	70	100	0	0	0
Scoter *(Melanitta* spp.*)*	3	‡	‡	100	0	0	0
White-winged Scoter *(Melanitta deglandi)*	1	‡	‡	100	0	0	0
Great Black-backed Gull *(Larus marinus)*	5	‡	‡	0	100	0	0
Herring Gull *(Larus argentatus)*	41	388	97	0	93	7	0
Black-legged Kittiwake *(Rissa tridactyla)*	13	163	41	0	92	8	0
Razorbill *(Alca torda)*	48	797	199	56	44	1	2
Common Guillemot *(Uria aalge)*	26 814	88 279	22 070	81	16	1	2
Brunnich's Guillemot *(Uria lomvia)*	6	‡	‡	100	0	0	0
Black Guillemot *(Cepphus grylle)*	185	2001	500	17	81	2	0
Atlantic Puffin *(Fratercula arctica)*	1674	4720	1180	45	48	7	0
Total Birds	30 124	109 838	27 480	79	18	1	2
Harp Seal *(Pagophilos groenlandicus)*	371	2983	746	82	0	0	18
Harbour Seal *(Phoca vitulina)*	29	117	29	86	10	3	0
Hooded Seal *(Cystophora cristata)*	4	‡	‡	100	0	0	0
Harbour Porpoise *(Phocoena phocoena)*	41	558	140	90	5	5	0
Dolphin (spp.)†	5	‡	‡	0	100	0	0
Pilot Whale *(Globicephala melaena)*	4	‡	‡	100	0	0	0

*Proportion of recorded catch taken in cod gill-nets (Cgn), salmon gill-nets (Sgn), cod traps (Ct), and flounder gill nets (Fgn).
†Probably *Lagenorhynchus albirostris* or *L. acutus.* ‡Insufficient data for extrapolation.

1). The proportion of puffins, razorbills, and common guillemots taken in cod gill-nets (45, 56, and 81%, respectively, Table 1) appears to be related to diving ability (Table 2), although differential habitat use (inshore vs. offshore; Piatt (1987) may also have influenced proportions taken in different types of gear.

Pursuit divers were also the most common seabird species taken in salmon drift-nets off west Greenland (loons, greater shearwater, and all Atlantic alcids; Christensen & Lear 1977), and in the north Pacific (three shearwater and eight alcid species; Ainley *et al.*, 1981; Carter & Sealy, 1984); and in salmon, herring and cod gill-nets off Ireland (mostly razorbills; Bibby, 1972), and Norway (common guillemots, puffins, razorbills and great cormorants (*Phalacrocorax carbo*); Brun, 1979; Olden *et al.*, 1985).

All harp seals were taken in relatively deep-set (Table 2) cod and flounder gill-nets (Table 1) set up to 100 km from shore; reflecting the offshore distribution of this pinniped (Sergeant, 1964). In contrast, harbour seals and harbour porpoises reside near shore in summer (Leatherwood *et al.*, 1976; Boulva & McLaren, 1979), and most were taken in relatively shallow-set cod gill-nets (Table 1 and 2).

3. The degree of aggregation at which different species forage influenced the composition of net catches. In general, highest catches (Table 1) were observed for species which form high-density feeding aggregations like common guillemots, shearwaters, puffins, gannets, harp seals, and harbour porpoises. It may be that nets are less visible to animals diving and feeding in dense groups, or that the probability of entangling large numbers is simply higher when feeding groups are dense.

For example, about 75 000 and 225 000 pairs of common guillemots and Atlantic puffins, respectively, breed at the Witless Bay Seabird Sanctuary in eastern Newfoundland (Fig. 1). Despite their numerical dominance, however, catches of puffins in this area were always an order of magnitude less than common guillemot catches. Studies of foraging behaviour at sea indicate that common guillemots form larger, denser feeding flocks than puffins (Piatt, 1987). This behaviour is reflected in the fact that the average net-catch of common guillemots was four times that of puffins (Piatt & Nettleship, 1985). The largest incident of puffin net-mortality observed at Witless Bay involved about 80 puffins whereas up to 1500 common guillemots have been taken in a single set of nets.

Catches in other regions have also been dominated by high-density foragers. In Greenland, Brunnich's guillemots (93%) and dovekies (*Alle alle*, 5%) comprised the vast majority of net-killed birds (Christensen & Lear, 1977). In Monterey Bay, California, common guillemots (42%), sooty shearwaters (39%), and surf scoters (*Melanitta perspicillata*, 6%) were most frequently killed in nets (Anon, 1982). Species with the highest at-sea densities in the north Pacific, including short-tailed shearwaters (43%), sooty shearwaters (20%), and tufted puffins (*Lunda cirrhata*, 17%), accounted for most (80%) of the seabirds taken in nets there (Ainley *et al.*, 1981). Similarly for marine mammals, harbour porpoises were the cetacean most commonly caught in nets off west Greenland (98%, Christensen & Lear, 1977), and off the coasts of Washington (Beach *et al.*, 1981) and California (Heneman, 1983). Of 112 cetaceans taken in nets off the northeast U.S. coast in 1977–1985 (Waring *et al.*, 1985), most were highly social pilot whales (51%) and common dolphins (*Delphinus delphinus*, 36%).

Spatial and Temporal Aspects of Net-mortality

The greatest numbers of marine animals are killed in net when human fishing activities coincide temporally and spatially with animal foraging concentrations. In Newfoundland, the salmon gill-net fishery operates from mid-May to early July, and the inshore cod gill-net fishery is conducted between early June and mid-August. Salmon fishing effort is fairly constant until salmon become scarce inshore (mid-July). The inshore cod gill-net fishery peaks, however, during about a 4–6 week period from mid-June to late July which corresponds to the period in which capelin occur inshore for spawning on coastal beaches. These small (10–20 cm) fish are the dominant summer prey for cod as well as for many seabirds and marine mammals in eastern Newfoundland (Brown & Nettleship, 1984;

TABLE 2.

Numbers of marine birds and mammals caught at different depths*.

Species	Total no.†	Number caught at depth (m) interval: 0–10	10–20	20–30	30–50	50–70	70–100	>100
Common Loon	5	3	—	1	1	—	—	—
Greater Shearwater	388	218	153	17	—	—	—	—
Sooty Shearwater	22	14	4	4	—	—	—	—
Cormorant	2	—	1	1	—	—	—	—
Common Eider	18	—	6	12	—	—	—	—
Razorbill	15	1	5	2	3	—	3	1
Common Guillemot	16 309	3271	3198	3202	1440	1658	2951	589
Black Guillemot	50	21	19	6	3	1	—	—
Atlantic Puffin	1188	499	275	318	86	10	—	—
Harp Seal	43	—	—	11	20	9	3	—
Harbour Seal	6	1	3	1	—	—	1	—
Harbour Porpoise	23	3	17	3	—	—	—	—

*More detail on diving depths of alcids may be found in Piatt & Nettleship (1985).
†Total no. of records for which depth information was obtained.

Carscadden, 1984). Most capelin predators move inshore to forage on the dense spawning schools and this is when they are taken incidentally in fishing nets concentrated alongshore.

Thus the majority of shearwaters, gannets, common guillemots, puffins, harbour seals, and harbour porpoises were taken during a 4–6 week period in each year, and the exact timing depended on the chronology of inshore capelin spawning. Most of the remaining species (Table 1) were caught only incidentally throughout the period when nets were in the water. The entrapment of large cetaceans (e.g., humpback whales, *Megaptera novaeangliae*) in fishing gear also peaks during the capelin spawning period (Lien, 1980).

During the capelin period, daily catches of birds and mammals were extremely variable both temporally and spatially. Gill-nets that caught hundreds of birds one day were often empty the next, and different nets set close to each other did not necessarily catch comparable numbers of birds. These extreme variations in catch were probably due to temporal and spatial variability in capelin abundance, as well as the tendency for certain species to forage in dense groups.

For those species which feed heavily on capelin, the magnitude of net-mortality in different years was a function of the annual abundance of capelin. Hydroacoustic surveys conducted around the Witless Bay Seabird Sanctuary indicated there was a steady decline in the abundance of capelin in nearshore waters from 1982 to 1984 (Piatt, 1987). Correspondingly, there was a marked decline in the estimated catches of greater shearwaters, gannets, common guillemots, puffins, and harbour porpoises between 1982 and 1984 (Table 3). Catches of species with less or no dependence on capelin (e.g., loons, herring gulls, black guillemots, harp seals) did not vary in accord with capelin abundance (Table 3). This relationship appears to be straightforward: the greater the abundance of capelin inshore, the greater the number of predators available for entanglement in nets (fishing effort remained relatively constant between years).

The magnitude of catches was also a function of the spatial distribution of fishing effort. In particular, guillemots and puffins were caught in greatest numbers around their breeding colonies or in adjacent foraging areas. Most catches (over 80%) of Witless Bay birds occurred within 20 km of the colonies (Fig. 1), and catch-per-effort decreased quickly with distance away from the islands (log [no. caught/net-day] = −0.28 (km) + 0.14; $r = 0.37$, $df = 822$, $F = 131.7$, $p < 0.0001$). Although maximum foraging ranges varied between years, the vast majority of common guillemots and puffins were caught within 40 and 20 km off the islands, respectively. Similarly for colonies at Cape St. Mary's and Baccalieu Island (Fig. 1), most alcids were taken within 40 km of their colonies. On the northeast coast, however, birds from Funk Island were caught in great numbers around the western head of Bonavista Bay (Fig. 1), some 40–80 km from Funk Island.

TABLE 3

Estimated net-kill of selected species and relative abundance of capelin in eastern Newfoundland, 1982–1984. The relative inshore abundance of capelin was estimated from hydroacoustic surveys in eastern Newfoundland (Piatt, 1987).

Species	1982	1983	1984
Capelin	20.9	7.5	1.0
Common Loon	174	232	153
Greater Shearwater	1870	1548	754
Northern Gannet	747	581	220
Herring Gull	30	195	79
Razorbill	232	285	236
Common Guillemot	38 278	26 445	12 471
Black Guillemot	476	551	710
Atlantic Puffin	1503	1142	697
Harp Seal	743	587	793
Harbour Porpoise	168	138	112

Most marine mammals were also caught over brief periods where mammals and fishing activities overlapped. Most harp seals were taken by the middle-distance gill-net fishing fleet off the northeast coast in May and June. Most (91%) harp seals taken were immatures (2–3 years), presumably stragglers from the overwintering population which migrates north to arctic breeding grounds in late spring (Sergeant, 1964).

The temporal and spatial patterns of net-mortality observed in Newfoundland appear to be quite typical in other regions as well. Ainley *et al.*, (1981) found that catch rates for guillemots and puffins in the north Pacific declined logarithmically with distance from colonies in the Aleutian Islands. Off west Greenland, most Brunnich guillemot net-mortality occurred in September (64%) and October (22%) as guillemots staged on shallow offshore banks during migration (Christensen & Lear, 1977; Piatt & Reddin, 1984). Periods of exceptionally high catches probably resulted from the combined concentration of capelin, salmon, guillemots, and salmon fishing activity in relatively small areas (Piatt & Reddin, 1984). In California, the vast majority of shearwaters (95%) and common guillemots (78%) killed in nets in Monterey Bay were taken in only two months (July and August). Fishing effort there was fairly consistent throughout the year and peaks in guillemot and shearwater catch correspond to the migration period of these birds in the bay (Anon, 1982). Other resident species (e.g., cormorants) were taken in low numbers throughout the year. In Norway, the great majority of about 10 000 common guillemots drowned in nets during 1981–1983 were taken in January and February (Peterz & Olden, 1984). In all the above examples, there was enormous temporal and spatial variability in catch rates, especially during peak periods of catches. As in the Newfoundland situation, this was probably due to daily variability in prey abundance and distribution (Peterz & Olden, 1984; Piatt & Reddin, 1984).

Impact of Net-mortality on Populations

At present, it is not clear how much impact net-mortality is having on marine bird and mammal populations in Newfoundland. For some species (shearwaters, petrel, cormorant, eider, scoters, gulls, harp seal, hooded seal, dolphin, and pilot whale), the estimated mortality is probably insignificant in comparison to total population sizes. For other species (common loon, black guillemot, harbour porpoise) catch estimates seem quite high but we have few data on total population sizes with which to assess the significance of net-mortality. Given that our surveys covered only limited areas of eastern Newfoundland, the catch of species with widely dispersed populations (e.g., loon, gulls, black guillemots, seals and harbour porpoise) is undoubtedly greater than our estimates indicate.

For several species, however, the impact of net-mortality can be assessed with some confidence. About 20 000 gannets breed at three locations in Newfoundland (Nettleship, 1980), and on average about 2.1% of this population is killed in nets annually (assuming that all net-killed birds were adults). Gannet net-mortality is most common, however, on the northeast coast, and mostly affects birds from Funk Island. Based on regional estimates, about 9.3% of the Funk Island population was killed in nets in 1982 alone. About 1600 razorbills breed in Newfoundland (Nettleship, 1980), and on average (assuming that all birds were adults) 12.4% of this population was killed annually in nets from 1981–1984 (Table 1). This mortality rate exceeds most estimates of annual adult mortality for razorbills in stable populations in the north Atlantic (about 10%; Hudson, 1985), and is, therefore, clearly cause for concern. Of the approximately 800 000 common guillemots breeding in Newfoundland (Nettleship, 1980), about 22 000 (72% adult) were killed annually in nets, or about 2.0% of the total adult population. Local impact, however, could be much greater. In 1982, an estimated 5.7% and 16.3% of adult common guillemot populations at Witless Bay and Cape St. Mary's were killed in nets. These net-mortality rates are significant because adult mortality rates in stable north Atlantic common guillemot populations average about 12% per annum (Hudson, 1985) and additional unnatural mortality results from hunting (Gaston *et al.*, 1983) and oil pollution (Piatt *et al.*, 1985). In contrast, the impact of net-mortality on puffin populations appears minimal because, on average, only 0.2% of the total adult population (540 000 individuals) is killed annually in nets. Finally, the net-kill of harbour seals on the south-eastern coast represents, on average, an annual mortality rate of about 2.8% of the total adult population in this area (about 910 individuals; Beck, 1983). Many of the seals taken, however, may have been juveniles (J. Lawson, pers. comm.), which would lessen the estimated impact on the population. In any case, it is not known what the average annual mortality rate is for harbour seals, and whether net-mortality represents a significant proportion of total mortality.

Based on recent (1970–1985) seabird population censuses (e.g., Brown *et al.*, 1975; Nettleship, 1980; Piatt & McLagan, 1987), we have been unable to establish a direct link between net-mortality and seabird population fluctuations in Newfoundland. Given the variety of mortality factors, large sizes of colonies, and difficulties in censusing, the impact of net-mortality (or any other source of mortality) on populations may not be evident for many years to come (Evans & Nettleship, 1985). Despite this, some of the above estimates of net-mortality clearly indicate cause for concern and a need for continued monitoring of specific populations.

There is little doubt that net-mortality has the potential to inflict serious damage to some marine animal populations. Net-mortality was a major contributor to the large declines of Brunnich's guillemot populations at west Greenland (Evans & Waterston, 1976; Nettleship & Evans, 1985) and in the Canadian arctic (Nettleship & Evans, 1985). Net-mortality seriously threatens marbled murrelet (*Brachyramphus marmoratus*) populations in British Columbia (Carter & Sealy, 1984), and in California, net-mortality has been implicated as the major cause for a recent decline of common guillemots breeding on the Farallon Islands (from 88 000 in 1982 to 42 500 in 1984; Heneman, 1981, 1983, 1984; Anon, 1982; Carter, 1986).

Mitigation of Net-mortality

Drastic reductions in net-mortality of some non-target species could be achieved with action based on current knowledge. Our studies indicate that: 1. species at greatest risk are those marine predators which a, pursue their prey underwater, and b, aggregate in dense foraging groups; 2. greatest net-catches occur during periods when prey occur in areas frequented by fishermen and predators; 3. the magnitude of net-mortality for many predators may be a function of prey abundance; and 4. net-mortality decreases with distance from colonies of seabirds vulnerable to net-entanglement. It is impractical to advocate the elmination of gill-net fisheries, but enforced regulations on net-types, by-catch quotas (like those currently applied to non-target fish species), fishing seasons, and the closure of fisheries in particularly sensitive areas (e.g., around seabird colonies or seal rookeries), could immediately reduce the impact of net-mortality on many marine animal populations.

It is now clear that hundreds of thousands, if not millions, of non-target marine animals are being killed annually in a variety of Atlantic and Pacific fisheries. The negative impact of this mortality is already evident in some populations and we can expect to see future declines in other populations if net mortality continues unabated. Future research efforts should be directed at continued monitoring of known problem areas and of affected populations, and construction of population models for affected species. An increased education effort should be directed at government agencies responsible for fisheries, and the fishing industry itself, so that long-term management plans incorporate appropriate measures to deal with the problem.

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